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Annex E — High-Velocity Object Identification for QHD

Scope

Annex E extends the Quantum Hash Descriptor (QHD) program beyond single-state identity and A-to-B transfer characterization so that the framework can identify and classify objects moving at high velocity under explicitly declared physical and observational assumptions. Phase A established deterministic state identity at a single epoch, while the subsequent methodological annexes introduced validation logic, transfer descriptors, and the requirement for a dedicated dynamical layer when trajectory fidelity is under evaluation [file:134][file:133][file:131][file:132].

The purpose of Annex E is to formalize a specialized protocol layer for fast-moving objects whose motion cannot be treated adequately by slow-evolution assumptions or simple planet-like trajectory models. This includes fragments, ejecta, shocks, knots, and other compact moving structures whose kinematic regime is materially different from standard orbital baselines [file:132][web:149].

Scientific motivation

Observations of high-velocity debris and compact structures and related ejecta show that debris can move at thousands of kilometers per second, and Type II supernovae commonly exhibit expansion velocities on the order of about 10,000 km/s early in their evolution, with values decreasing over time [web:137][web:144][web:149]. Observational studies of remnant ejecta knots and blobs also report characteristic high-velocity structures in the several-thousand-km/s range, confirming that a dedicated identification layer for fast-moving material is scientifically justified [web:143][web:148][web:151].

Because these regimes differ sharply from ordinary planetary motion, a protocol intended to identify such objects must give special weight to velocity scale, uncertainty growth, sampling cadence, and model-class declaration. Annex E is therefore not merely a minor extension of Phase B but a regime-specific refinement of the QHD architecture for high-velocity phenomena [file:132][web:149].

Conceptual objective

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Annex E answers the following question: “How can a moving object with a high-velocity kinematic regime be identified deterministically, reproducibly, and comparably across observations, reconstructions, or simulations, even when the trajectory is only partially observed?” [file:132][web:149]

This requires three capabilities:

- Deterministic identity of the object at observed epochs.
- Deterministic identity of the transfer segment or trajectory hypothesis.
- Deterministic classification of the object as belonging to a declared high-velocity regime.

Annex E therefore adds a **velocity-regime layer** to the existing Phase A and Phase B structures.

Annex E object structure

The Annex E object may be expressed as:

$$\Omega_o = (\Theta_o(A \rightarrow B), \mathcal{V}_o, \mathcal{R}_o, \mathcal{Q}_o)$$

where:

- $\Theta_o(A \rightarrow B)$ is the Phase B transfer object.
- $\mathcal{V}_o$ is the high-velocity descriptor.
- $\mathcal{R}_o$ is the regime classification layer.
- $\mathcal{Q}_o$ is the confidence and observability layer.

This structure keeps backward compatibility with the previously defined state and transfer logic while introducing the additional information needed for high-velocity identification [file:131][file:132][file:134].

High-velocity descriptor

A practical Annex E velocity descriptor may be defined as:

$$\mathcal{V}_o = (v_r, v_t, v_{3D}, a_{eff}, \mu, z_k, \eta_v)$$

where:

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- v_r is the radial velocity component, when spectroscopically available.
- v_t is the transverse velocity inferred from proper motion and distance when available.
- v_{3D} is the reconstructed total speed.
- a_{eff} is an effective acceleration or deceleration estimate under the declared model.
- μ is angular proper motion when applicable.
- z_k is a kinematic redshift or Doppler-related summary where appropriate.
- η_v is a normalized velocity-regime indicator.

This descriptor is intended to capture not only speed but also the measurement pathway by which speed is known or inferred.

Velocity-regime indicator

The velocity-regime indicator should classify the object relative to a declared reference population rather than relying on an absolute universal threshold. A useful normalized quantity is:

$$\eta_v = \frac{v_{3D}}{v_{ref}}$$

where v_{ref} is a protocol-defined reference speed for the object class, observational domain, or validation campaign. This allows Annex E to distinguish moderate, elevated, and extreme kinematic behavior within a declared context rather than claiming one threshold is valid for all astrophysical systems [file:132].

A minimum regime classification policy may use categories such as:

Regime	Condition
Standard	$\eta_v < 1$
High-velocity	$1 \leq \eta_v < \eta_{ext}$
Extreme high-velocity	$\eta_v \geq \eta_{ext}$

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The exact value of η_{ext} should be declared by protocol version and object class rather than assumed silently.

Observational inputs

Annex E should support heterogeneous data inputs, because high-velocity objects are often identified through multi-modal evidence rather than through a single clean state vector. Supported evidence classes may include:

- Spectroscopic line shifts.
- Proper motion measurements.
- Multi-epoch imaging.
- Distance estimates.
- Model-assisted reconstruction.
- Simulation-linked synthetic observables.

This is consistent with the methodological requirement, already established in prior annexes, that reproducibility depends on explicit source declaration, time handling, frame policy, and dynamical assumptions [file:131][file:132][file:133].

Metadata extension for Annex E

Annex E requires a richer metadata layer than Phase B. A recommended minimum structure is:

Field	Purpose
objectname	Tracked object or knot label
objectclass	Debris, ejecta knot, fragment, pulsar, compact clump, etc.
velocityclass	Standard, high-velocity, extreme high-velocity
epochA	Initial epoch
epochB	Final epoch
referenceframe	Spatial frame

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timescale	Declared time policy
vr_source	Source of radial velocity estimate
vt_source	Source of transverse velocity estimate
distance_source	Source of distance estimate
dynamicmodel	Declared propagation or reconstruction model
observabilityclass	Direct, inferred, hybrid, reconstructed
uncertaintyclass	Confidence and uncertainty policy
serializationversion	Annex E protocol version

In Annex E, these fields are not optional presentation details; they are part of the object identity conditions because the same moving structure can be classified differently under different observational assumptions [file:131][file:132].

Annex E transfer and state chaining

A high-velocity object should preferably be represented as a chain of states rather than a single endpoint pair whenever data allow. The chain form may be written as:

$$\mathcal{C}_O = (\Xi_O(t_0), \Xi_O(t_1), \dots, \Xi_O(t_n))$$

with an associated transfer chain hash:

$$h_{q,c}^{chain} = \text{SHA3-256}(\text{Serialize}(\mathcal{C}_O, \mathcal{V}_O, \mathcal{R}_O, \mathcal{M}_O))$$

This approach is particularly important for high-velocity objects because sparse sampling can hide rapid kinematic changes or produce misleading transfer summaries if only two states are used [file:132][web:148].

Identification logic

A Annex E object should be considered successfully identified only if all of the following conditions are satisfied:

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1. The endpoint or sampled states are individually conformant under the Phase A logic [file:133][file:131].
2. The transfer relation between states is conformant under the Phase B logic [file:132].
3. The high-velocity descriptor $\mathcal{V}_o$ is reproducibly constructed from declared measurements or reconstructions.
4. The regime classification $\mathcal{R}_o$ is computed under an explicit threshold policy.
5. The final canonical serialization yields a stable digest across repeated executions.

This layered logic follows the same methodological spirit as Annex B, where intermediate quantities and canonical serialization must both be reproducible for protocol conformance [file:131].

Validation strategy

A proper Annex E validation program should test both synthetic and observational cases.

Synthetic validation

Synthetic validation should use simulated high-velocity trajectories with known ground truth so that the protocol can be tested for:

- Correct recovery of velocity class.
- Stability of transfer identification.
- Sensitivity to sampling cadence.
- Sensitivity to uncertainty inflation.
- Robustness of serialization and digest generation.

Observational validation

Observational validation should use multi-epoch high-velocity objects for which radial, transverse, or combined kinematic estimates are available from the literature or archival data. Published studies of remnant ejecta, knots, and blobs provide a scientifically relevant validation environment because they explicitly quantify fast motions and often link kinematics to spatially resolved structures [web:143][web:148][web:151].

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High-velocity debris and compact structures

High-velocity debris and compact structures is an appropriate canonical use class for Annex E because observed expansion velocities are commonly in the several-thousand to roughly ten-thousand km/s regime, especially at earlier stages, and remnant studies show that ejecta substructures may retain measurable high-velocity signatures over time [web:137][web:144][web:149]. This makes such debris materially different from slow-moving orbital bodies and therefore suitable for a regime-specific identification layer [web:143][web:148].

In this context, Annex E should not initially claim exact physical recovery of the full hydrodynamic explosion history. Rather, it should claim a more rigorous and defensible capability: deterministic identity of a high-velocity moving object under explicitly declared kinematic, observational, and dynamical assumptions [file:132][web:149].

Scientific limits

Annex E is an identification and classification layer, not by itself a complete hydrodynamic solver. A conformant Annex E record can therefore be scientifically useful even when the underlying physical reconstruction remains approximate. This is consistent with the broader QHD philosophy already reflected in the prior annexes, where deterministic informational identity and reproducible provenance are treated as distinct from total physical completeness [file:133][file:132].

Accordingly, Annex E should initially support claims such as:

- Deterministic identification of high-velocity objects across epochs.
- Reproducible trajectory-segment hashing under declared assumptions.
- Regime-aware comparison between different fast-moving objects.
- Compatibility with future higher-fidelity dynamical or hydrodynamical engines.

It should not, at its first version, claim full recovery of all nonlinear physics governing every fast ejecta system.

Recommended manuscript statement

A technically defensible statement for the manuscript would be:

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“Annex E extends QHD with a high-velocity object layer that permits deterministic identification, transfer characterization, and regime-aware comparison of fast-moving structures under explicitly declared observational and dynamical assumptions. The framework is intended for objects whose kinematics depart materially from standard slow-evolution orbital baselines, including high-velocity debris and ejecta classes.” [file:132][web:149]

Development path

A rigorous development path for Annex E should proceed in the following order:

1. Define the canonical Annex E tuple and serialization policy.
2. Create synthetic high-velocity validation vectors.
3. Validate radial-only, transverse-only, and combined 3D velocity cases.
4. Validate regime classification reproducibility across protocol versions.
5. Test multi-epoch state chaining for fast-moving structures.
6. Apply the framework to observational high-velocity debris classes.

This order preserves methodological continuity with Annex D, Annex B, and Annex C while introducing a clearly scoped new capability [file:131][file:132][file:133][file:134].

Annex status

This text may serve as the formal conceptual definition of Annex E for the QHD program. It is suitable for inclusion in a scientific manuscript, technical concept note, or institutional proof-of-concept dossier as the extension of QHD toward deterministic identification of high-velocity moving objects under explicit kinematic and observational policies [file:131][file:132][file:133][file:134].

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